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<p>(21) International Application Number: PCT/GB91/01674 (22) International Filing Date: 27 September 1991 (27.09.91) (30) Priority data: 9021122.8 28 September 1990 (28.09.90) GB (71) Applicant (for all designated States except US): COOKSON GROUP PLC [GB/GB]; 130 Wood Street, London EC2V 6EQ (GB). (72) Inventors; and (75) Inventors/Applicants (for US only) : BUTCHER, Steven, John [GB/GB]; 16 The Paddocks, Yarnton, Kidlington, Oxon OX5 1TF (GB). HOBBY, James, David [GB/GB]; 12 Queen Elizabeth Close, Didcot, Oxon OX11 8TQ (GB). KINGS, Donald, Harry, Maguire [GB/GB]; Grange Farm, Station Road, Launton, Bicester, Oxon OX6 0DX (GB).</p>		<p>(74) Agent: BOULT, WADE & TENNANT; 27 Furnival Street, London EC4A 1PQ (GB). (81) Designated States: AT (European patent), BE (European patent), CA, CH (European patent), DE (European patent), DK (European patent), ES (European patent), FI, FR (European patent), GB (European patent), GR (European patent), IT (European patent), JP, LU (European patent), NL (European patent), NO, SE (European patent), US. Published <i>With international search report.</i></p>
<p>(54) Title: COMPOSITE MULTILAYER CERAMIC STRUCTURE</p> <p>(57) Abstract</p> <p>A composite multilayer ceramic structure which comprises in a single device a plurality of layers of an electrostrictive dielectric material separated by a plurality of electrode layers in which a first portion is adapted to operate as an electrostrictive actuator and a second portion, which is adjacent to the first portion and which is not inherently piezoelectric, is adapted to operate in the same way as a piezoelectric sensor.</p> <div data-bbox="878 1087 1523 1948"> </div>		

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⁺ Any designation of "SU" has effect in the Russian Federation. It is not yet known whether any such designation has effect in other States of the former Soviet Union.

COMPOSITE MULTILAYER CERAMIC STRUCTURE

The present invention relates to a composite multilayer ceramic structure and, in particular, to a controlled force or force limited multilayer ceramic actuator which comprises a combination of an electrostrictive actuator and sensor.

Multilayer ceramic actuators in which a plurality of layers of a dielectric material are separated by a plurality of electrode layers are known in the art. We have now developed a composite multilayer ceramic structure in which a multilayer electrostrictive ceramic actuator is combined with a sensor in a single device.

Accordingly, the present invention provides a composite multilayer ceramic structure which comprises a plurality of layers of an electrostrictive dielectric material separated by a plurality of electrode layers in which a first portion is adapted to operate as an electrostrictive actuator and a second portion, which is adjacent to the first portion and which is not inherently piezoelectric, is adapted to operate in the same way as a piezoelectric sensor.

The composite multilayer ceramic structure of the present invention is a controlled force or force limited electrostrictive actuator which comprises a stack of a plurality of layers of an electrostrictive dielectric material separated by a plurality of electrode layers, alternate electrodes in a first portion of the stack being connected to positive or negative potential and means to apply a voltage thereto, alternate electrodes in a second portion of the stack being connected to positive or negative potential and means to apply a bias voltage thereto, means to measure the charge produced by the second

portion of the stack and means to adjust the voltage applied to the first portion of the stack.

In the composite multilayer structure of the present invention the second portion adapted to
5 operate as a sensor may be sandwiched between first and third portions which are adapted to operate as electrostrictive actuators.

The first portion, and the third portion of the composite composite multilayer ceramic structure when
10 present, are adapted to operate as electrostrictive actuators.

The material which is used as the electro-
strictive dielectric material in the different
portions of the structure may be the same or
15 different, although it is preferred to use the same material. For example, the same dielectric material may be used for the different portions of the structure, providing that it is a material in which piezoelectricity can be induced, for example by the
20 application of a bias field.

The present invention also includes within its scope a method of producing a controlled force or force limited multilayer ceramic actuator which
25 comprises forming a stack of a plurality of layers of an electrostrictive dielectric material separated by a plurality of electrode layers, operating a first portion of the stack as an electrostrictive actuator by connecting alternate electrodes in the first
portion of the stack to positive or negative
30 potential and applying a voltage thereto, and inducing piezoelectricity in a second portion of the stack so that it generates a charge which is proportional to the force produced by the actuator.

The charge, Q , generated by the sensor portion of
35 the structure may be measured by conventional techniques. Measurement of the charge enables the

force acting on the sensor portion of the structure to be determined and the force applied by the electrostrictive actuator may be controlled or limited by varying the voltage which is applied to the first (and optionally third) portion(s) of the stack.

The controlled force or force limited actuator of the present invention may be used in mechanised devices, such as precision robots.

The present invention will be further described with reference to the accompanying drawing in which:-

Figure 1 is a diagram of a multilayer ceramic structure in accordance with the invention which is formed from a single electrostrictive ceramic material; and

Figure 2 is a graph in which the output of the sensor portion of a device according to the invention is plotted as a function of the applied load.

Referring to Figure 1, the actuator comprises a plurality of layers of the same dielectric material 1 which are separated by a plurality of electrode layers 2. The structure, as shown, is essentially divided into two portions, the first portion A operating as an electrostrictive actuator whilst the second portion B acts as a piezoelectric sensor. Alternate electrodes in portion A are connected together to a positive potential 3 or a negative potential 4. A voltage is thereby applied to the electrostrictive portion A of the structure. The application of a voltage across the electrostrictive portion A of the structure produces strain and generates force which is indicated by the arrows F on the figure. The alternate electrodes of the portion of the structure B are connected to a bias voltage source 5 and a bias voltage applied thereto. The bias field induces piezoelectricity and induced

piezoelectric dipoles 6 are shown by the arrows in the Figure. The piezoelectric sensor portion B of the structure is thereby placed under stress and
5 generates an electric charge Q which is measured by conventional means, not shown. Measurement of the charge Q enables determination of the force F acting on the piezoelectric sensor portion B of the
10 structure, thus allowing the force applied by the actuator portion A of the structure to be controlled or limited by varying the voltage applied thereto.

Figure 2 is a graph in which the output of the sensor portion of a device as described with reference to Figure 1 was plotted as a function of
15 the applied load. The sensor portion of the device comprised 10 layers, the thickness of the dielectric layers being 125 micrometres and the thickness of the electrode layers being 10 micrometres. The area of each layer of the device was 10 X 9 mm. The D.C.
20 voltage (bias voltage) was 30 V.

The output signal is suitable for use in a standard feedback circuit, enabling the combined device to be used to control or limit the load which it applies.
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CLAIMS:

1. A composite multilayer ceramic structure
5 which comprises in a single device a plurality of
layers of an electrostrictive dielectric material
separated by a plurality of electrode layers in which
a first portion is adapted to operate as an
electrostrictive actuator and a second portion, which
10 is adjacent to the first portion and which is not
inherently piezoelectric, is adapted to operate in
the same way as a piezoelectric sensor.

2. A composite multilayer ceramic structure as
15 claimed in claim 1 wherein the second portion is
positioned between first and third portions which are
adapted to operate as electrostrictive actuators.

3. A composite multilayer ceramic structure as
20 claimed in claim 1 or claim 2 wherein the same
dielectric material is used in the first and second
portions, and the third portion when present.

4. A composite multilayer ceramic structure as
25 claimed in claim 1 or claim 2 wherein different
electrostrictive dielectric materials are used for
the first (and third) portion(s) adapted to operate
as an electrostrictive actuator, and the second
portion adapted to operate in the same way as a
30 piezoelectric sensor.

6. A method of producing a controlled force or
force limited multilayer ceramic electrostrictive
actuator which comprises forming a stack of a
35 plurality of layers of an electrostrictive dielectric
material separated by a plurality of electrode

layers, operating a first portion of the stack as an electrostrictive actuator by connecting alternate electrodes in the first portion of the stack to positive or negative potential and applying a voltage thereto, and inducing piezoelectricity in a second portion of the stack so that it generates a charge which is proportional to the force produced by the actuator.

6. A method as claimed in claim 5 wherein the same dielectric material is used in the first and second portions of the stack.

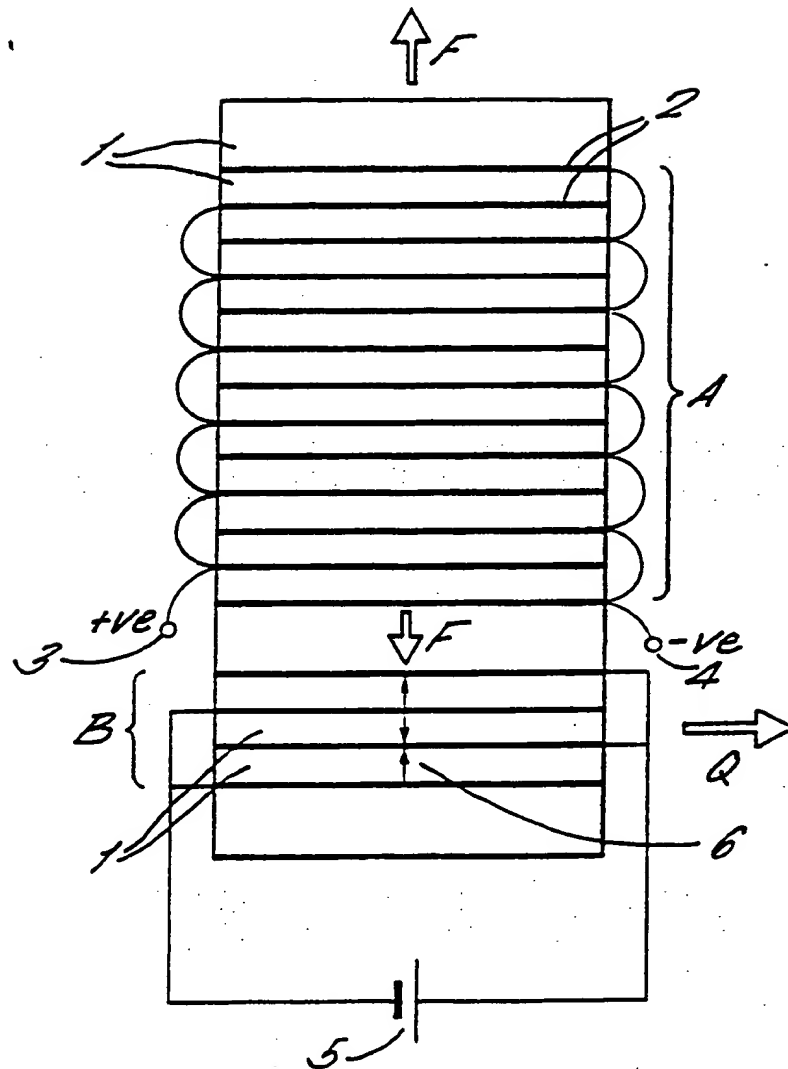
7. A method as claimed in claim 5 or claim 6 wherein piezoelectricity is induced in the second portion of the stack by applying a bias field thereto.

8. A method as claimed in any one of claims 5 to 7 wherein the force applied by the electrostrictive actuator is controlled by varying the voltage which is applied to the first portion of the stack.

9. A controlled force or force limited multilayer ceramic electrostrictive actuator which comprises a stack of a plurality of layers of an electrostrictive dielectric material separated by a plurality of electrode layers, alternate electrodes in a first portion of the stack being connected to positive or negative potential and means to apply a voltage thereto, alternate electrodes in a second portion of the stack being connected to positive or negative potential and means to apply a bias voltage thereto, means to measure the charge produced by the second portion of the stack and means to adjust the voltage applied to the first portion of the stack.

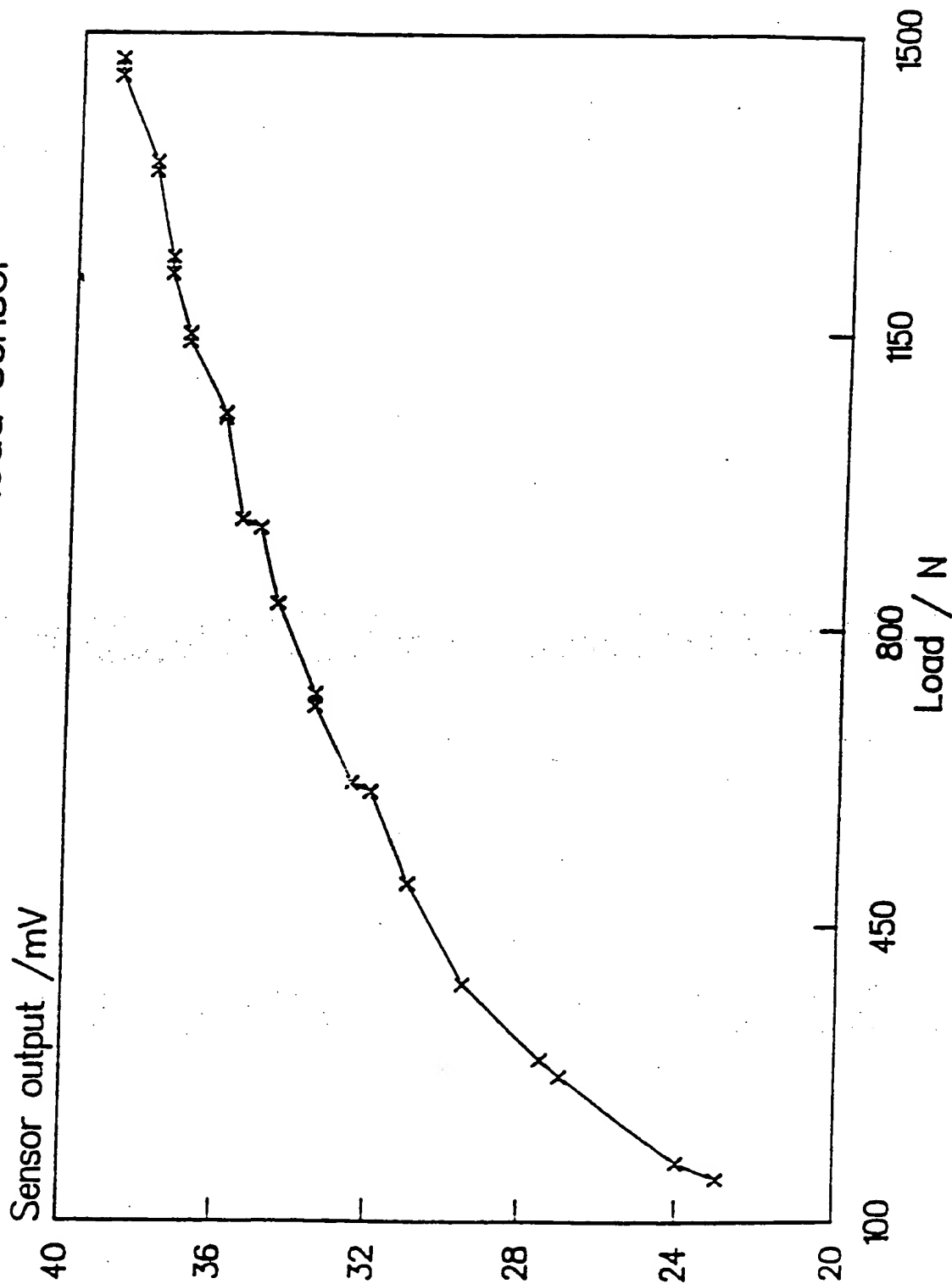
1/2

FIG. 1.



2/2

FIG. 2. Biased electrostrictive load sensor



INTERNATIONAL SEARCH REPORT

International Application No PCT/GB 91/01674

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) ⁵ According to International Patent Classification (IPC) or to both National Classification and IPC IPC5: H 01 L 41/08						
II. FIELDS SEARCHED <div style="text-align: center; border-top: 1px solid black; border-bottom: 1px solid black;">Minimum Documentation Searched⁷</div> <table style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 25%; border-bottom: 1px solid black;">Classification System</td> <td style="border-bottom: 1px solid black;">Classification Symbol⁶</td> </tr> <tr> <td style="height: 40px; vertical-align: bottom;">IPC5</td> <td style="vertical-align: bottom;">H 01 L, H 04 R</td> </tr> </table> <div style="text-align: center; border-top: 1px solid black; border-bottom: 1px solid black;">Documentation Searched other than Minimum Documentation to the extent that such Documents are included in Fields Searched⁸</div>			Classification System	Classification Symbol ⁶	IPC5	H 01 L, H 04 R
Classification System	Classification Symbol ⁶					
IPC5	H 01 L, H 04 R					
III. DOCUMENTS CONSIDERED TO BE RELEVANT⁹						
Category *	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³				
X	Patent Abstracts of Japan, Vol 12, No 3, E570, abstract of JP 62-165380, publ 1987-07-21 NEC CORP.	1,3				
Y	--	5-9				
Y	US, A, 4523121 (S. TAKAHASHI ET AL) 11 June 1985, see figures 3,6,24	5-9				
A	US, A, 4667127 (P.W. KREMPL ET AL) 19 May 1987, see column 1, line 8 - line 27; figure 3	1-9				
<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p>* Special categories of cited documents:¹⁰</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> </div> <div style="width: 45%;"> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance, the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance, the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"&" document member of the same patent family</p> </div> </div>						
IV. CERTIFICATION						
Date of the Actual Completion of the International Search 14th December 1991	Date of Mailing of this International Search Report <div style="text-align: right; font-size: 1.2em;">20 DEC 1991</div>					
International Searching Authority <div style="text-align: center; font-weight: bold;">EUROPEAN PATENT OFFICE</div>	Signature of Authorized Officer 					

**ANNEX TO THE INTERNATIONAL SEARCH REPORT
ON INTERNATIONAL PATENT APPLICATION NO. PCT/GB 91/01674**

SA 51719

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on 31/10/91
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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US-A- 4523121	11/06/85	AU-B- 553391	10/07/86
		AU-D- 1442283	17/11/83
		DE-A- 3378393	08/12/88
		EP-A-B- 0094078	16/11/83
		JP-C- 1472361	27/12/88
		JP-A- 58196068	15/11/83
		JP-A- 58196069	15/11/83
		JP-B- 63034636	11/07/88
		JP-A- 58196070	15/11/83
		JP-A- 58196071	15/11/83
		JP-A- 58196072	15/11/83
		JP-A- 58196073	15/11/83
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		DE-A- 3318959	01/12/83
		JP-A- 58196078	15/11/83
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US-A- 4667127	19/05/87	AT-A-B- 382968	11/05/87
		CH-A-B- 664235	15/02/88

For more details about this annex : see Official Journal of the European patent Office, No. 12/82